ATTACHMENT 1

Task 1 Assessment Report:
Defining the Analysis Issues and Design Problems to Be Addressed by the Lake Tahoe Hydrologic Design Criteria

LAKE TAHOE, CALIFORNIA AND NEVADA

Prepared for:

SWQIC
Lake Tahoe Storm Water Quality Improvement Committee

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LAKE TAHOE BASIN HYDROLOGY STUDY
TASK 1 ASSESSMENT REPORT: ANALYZING HYDROLOGIC DESIGN CRITERIA USED IN THE LAKE TAHOE BASIN

LAKE TAHOE, CALIFORNIA AND NEVADA

EXECUTIVE SUMMARY

Purpose

The purpose of this document is to propose studies to the Storm Water Quality Improvement Committee (SWQIC) useful for developing hydrologic design criteria (HDC) important to addressing both traditional storm water control design and the development of best management practice strategies in the Lake Tahoe Basin. The Corps end-product will *not* be a completed design manual. It is a set of tools/products that can be incorporated into the new plan for hydrologic design as set forth in a future Lake Tahoe manual. After the Corps has completed the HDC scope, a significant amount of effort will still be needed to produce the final manual – perhaps an additional year of work.

This document will determine if the Corps currently proposed Scope of Work dated 17 September 2003 is suitable to meet the goals of SWQIC. See Appendix B for the Scope of Work. HDC developed by various federal, state, and local agencies was reviewed and key personnel in each agency contacted. On-going scientific research was also investigated.

The contribution of storm water runoff to non-point source pollution is a critical consideration in protecting Lake Tahoe water quality. The Tahoe Regional Planning Agency (TRPA) intends to address impacts of storm water runoff and the associated non-point source pollution by reducing (see TRPA 2002, pg. 3-1):

> *...loads of sediment and algal nutrients to Lake Tahoe; Meet sediment and nutrient objectives for tributary streams, surface runoff, and sub-surface runoff, and restore 80 percent of the disturbed lands.*

Consequently, there is a great benefit to be gained by having new hydrologic design criteria that not only address the traditional problem of sizing storm water conveyance systems and delineating the regulatory floodplain; but also consider the goal of mitigating the impact of non-point source pollution.

County and city agencies, Caltrans (California Department of Transportation), and Nevada Department of Transportation (NDOT) employ similar methods/models for estimating storm water runoff. However, the source of information for precipitation used to create design storms and estimation approaches used to obtain model parameters potentially make it difficult to obtain consistent design flow estimates for the study area. Investigations for developing consistent estimation method for the HDC should focus on the following areas:

- Different depth-duration-frequency curves obtained from various sources are used to develop design storms. A review of precipitation frequency in the Lake Tahoe Basin (study area) needs to be performed to develop recommendations for **regionally consistent** depth-duration-frequency curves.

- Watershed models generally assume that design precipitation is uniformly distributed across a drainage area (except for adjustments for elevation). In contrast, Placer County provides a storm areal pattern that is centered to produce maximum runoff for a particular runoff return interval. Some evaluation of the Placer County approach is needed to determine if it should be adopted study area wide.

- Snowmelt is considered in a very approximate manner but is known to be a major contributor to the volume and peak rates of runoff in the Tahoe Basin. There is potential value in considering a more sophisticated approach to modeling snowmelt.

- Methods for estimating loss rates, conveyance of direct runoff and channel flow are very similar among the agencies. Sources for parameter estimates of roughness, travel times, and antecedent watershed conditions vary. The basis for these estimates needs to be reviewed with an eye towards recommending a consistent estimation approach.

- The Placer County approach to parameter estimation is more conservative than the other agencies (e.g., the spatial distribution of a design storm and the wet antecedent conditions assumed for loss rates). The appropriate degree of conservatism should be an aspect of this investigation.

- As stated in the original Corps scope, "review ongoing studies with regard to BMP and TMDL studies in the project area."

Proposed Analyses/Products

The following paragraphs describe items the Corps believes will be useful for members of SWQIC. Not all of these products are typically found in a hydrologic design manual, but are considered useful in Lake Tahoe for their application to water quality or ecosystem restoration studies. Best Management Practices (BMPs) play a key role in the restoration of Lake Tahoe's water quality. BMPs are intended to help meet water quality objectives for a particular water body by meeting limits set by estimated total maximum daily loads (TMDLs). The BMPs currently prescribed by TRPA were developed prior to establishment of TMDLs for Lake Tahoe. The ongoing research in developing the Loading Simulation Program in C++ (LSPC) and Lake Clarity models by the Lahontan Regional Water Quality Control Board (LRWQCB) and Nevada Division of Environmental Protection (NDEP) is intended to establish TMDLs for the Lake Tahoe Basin. This would provide some basis for revising the presently recommended BMPs utilized in the Basin, and the development of new HDC could assist designers in meeting the TMDL assigned to Basin watersheds.

The Corps supports the efforts being undertaken by the LRWQCB and NDEP (SWQIC members), and it is the desire of the Corps to share information (such as it regional flow-duration curves) with LRWQCB and NDEP in the hopes it will provide valuable insights. Comparison of results from different methodologies is a normal practice of hydrology. The Corps suggests that differences between the hydrometeorology used for establishing regulatory TMDLs, and what may be utilized for BMP design, should be investigated to ensure that procedures are adopted that are not inconsistent or incompatible. It is recognized that different procedures may be appropriate for the two efforts, but more information is needed on the implications of these differences. The SWQIC endorsed this comparison in Spring 2004, and such a comparison may not be appropriate until a later date under a separate scope performed by others. Even though a comparison at this stage may seem too early, the two processes will merge at some point and all involved will need to clearly understand the differences.

Geographic information systems (GIS)

An extensive effort has already been made to develop GIS layers for the Lake Tahoe Basin. This information should be reviewed to determine what additional information could be provided. The U.S. Army Cold Region Research and Engineering Laboratory (CRREL) has an extensive inventory of remotely sensed data that might be useful to the TMDL study. At the very least, the data available on snow water equivalent will be useful for establishing antecedent conditions for simulating design precipitation events. Task 2 of the Corps SOW involves developing a GIS database.

Hydro-Met Data

As mentioned in the previous bullet, CRREL has a significant period of record of remotely sensed data that can be used to estimate snow water equivalent for the Lake Tahoe Basin. This information can be used to produce snow water equivalent (SWE) values useful for storm runoff modeling. Task 3.3 involves developing antecedent condition SWE maps for the Lake Tahoe basin that can be integrated into a new design manual. If energy budget methods are used in the LSPC model, then CRREL has extensive experience in using remotely sensed data to aid in these calculations.

Precipitation Analysis

A limited amount of gage information is available for the basin. This poses a significant problem for sub-watershed average estimates of precipitation important for both period of record simulations used to develop input for the LSPC model and determining the regional variation of precipitation depth-duration-frequency curves. Research efforts (major sponsors being LRWQCB and NDEP) are under way to use a physically based atmospheric model, MM5, to estimate period of record information at a relatively small grid-scale for the basin. An alternative approach was used to obtain this variation in the recently published depth-duration frequency curve study by the National Weather Service (see NOAA, 2004) covering the southwestern U.S. including the Tahoe Basin. A comparison of the two approaches, is recommended with respect to the precipitation values for different design storm conditions. This was a task agreed upon by SWQIC in spring 2004 to be performed by the Corps.

The Corps will review the NOAA study to determine its suitability for adoption into a new design manual for Lake Tahoe (Task 3.1 of Corps SOW). The Corps will develop a set of frequency based design storms with temporal and spatial distribution. This will be accompanied by corresponding antecedent snowpack and soil conditions (Tasks 3.3 and 3.4). This product can be integrated into the new design manual.

Watershed Model Development

Various precipitation runoff modeling approaches are used by local implementing agencies and state highway departments to address hydrologic design criteria for storm water conveyance, storage, and water quality BMPs. The various methods currently used by the various Basin implementers will be reviewed by the Corps and compared to the best available engineering practice as part of the Corps SOW. From this review, recommendations will be made regarding the hydrologic modeling methods to adopt that provide consistent and equitable estimates of design flows for the Lake Tahoe Basin (Task 5.0 of the Corps SOW). This task will not provide all the modeling data needed to make a completed design manual nor does it include a review of the TMDL modeling efforts recommended by SWQIC to occur at a later date. Clarification is given in Section 4.5 of this report.

Flood Frequency Analysis

Flood frequency analysis is directly relevant to storm water design issues, providing the discharge for an annual return interval or the elevation of the regulatory floodplain. This analysis has importance also for estimating TMDLs, providing calibration/verification information for the LSPC Model, and for comparing the regulatory floodplains with stream environmental zones (SEZs). Suggested methods for estimating TMDLs (see NDEP, 2003 and recent suggestions by the USDA National Sedimentation Laboratory) include integration of flow quantities from annual flow frequency curves and flow duration curves with the sediment concentrations associated with the flow quantities to estimate loads. The integration of water quality parameters with flow frequency curves or flow duration curves to estimate TMDLs is a distinct possibility that should be considered at a later date and for clarification, is not a part of the Corps SOW.

The development of the LSPC requires both calibration to existing gage data and verification of the calibrated model predictions. Flow-frequency estimates can be obtained at ungaged locations from regional relationships utilizing NOAA precipitation data. These regional estimates can be used either in verification or calibration of the period of record model simulations at ungaged locations. This would be done by comparing the flow frequency curves estimated from the period of record simulations (LSPC output) and regional estimates (performed by the Corps). This comparison is not a part of the Corps SOW, but should be considered at a later date.

SEZs play an important role in BMP strategies as “natural” treatment facilities. The boundaries of the SEZs do not necessarily correspond to the regulatory 100-year floodplain.

Development outside of this floodplain may interfere with strategies to use SEZs. Consequently, updated flow-frequency estimates will be important in defining the regulatory floodplain for comparison with SEZs.

Finally, a general use of flood frequency curves is to categorize a pre-project condition. For example, the peak annual flood frequency curve characterizes the flood runoff characteristics prior to a construction project. Traditionally, any urban development needs to mitigate impacts in the storm water drainage design (i.e., incorporating a detention pond) by preserving the flood-frequency curve. This is a no-impact principle, which can also be relevant to BMPs. A standard principle is that the water quality of runoff from a site should not be impacted by any actions taken in a particular area. The flood frequency curve is an essential piece of information that can be used in a BMP to aid in developing a no-impact design.

Given the importance of flood frequency estimates, the Corps of Engineers envisions performing flood frequencies studies for SWQIC that might involve: 1) selecting a flood frequency analysis procedure by performing a comparative study of the Bulletin 17B guidelines (the guidelines followed by federal agencies) and other well known estimation procedures; 2) examine if record augmentation at shorter record stations is possible using correlation with longer record stations; 3) perform a regional annual maximum flow frequency analysis; and, 4) develop regional regressions between basin characteristics and flood quantities applicable to ungaged areas (Task 4.1). The equations can be used to derive peak instantaneous and longer duration frequency curves.

The regional regression equations will be limited to use in non-urbanized areas of a minimum size (perhaps 200 acres or greater). Unfortunately, this may limit their use in some project specific BMP designs. For this category of BMP, some type of rainfall-runoff procedure will have to be utilized as discussed in Section 4.5 of the report. Nevertheless, the equations are still useful for calibrating portions of a larger watershed model that have subbasins sized for individual BMPs. Secondly, the equations can be used to quantify the pre-urbanized hydrologic conditions.

Flow-Duration Analysis

Flow-duration analysis has many of the same uses as flood-frequency analysis for application in BMPs described in the previous section. As such, the development of these relationships can be done using the data compiled for the flood frequency analysis. The Corps proposes to develop regional equations for estimating these curves for ungaged areas. This product is envisioned as an important tool with many potential uses including analyzing BMP effectiveness and ecosystem restoration. Further discussion is given in Section 4.7. This product is Task 4.3 of the Corps SOW. As stated in the discussion on flow-frequency, the regional flow-duration curve estimates will have restrictions on their use for urbanized or small drainages.

Low-Flow and Drought Analysis

Low-flow and drought analysis can be accomplished with the data that will be compiled as part of a flood frequency investigation. These analyses may not enter directly into BMP considerations, but it may be important in evaluating if an overall basin plan can meet water quality objectives for all potential hydrologic conditions. For example, there may be some potential for conflicts between water rights and water quality objectives that might be identified from a low-flow analysis. Characterizing the risk associated with low-flows or droughts is probably important for identifying these conflicts. This product is part of Task 4.2 of the Corps SOW. As stated in the discussion on regional flow-frequency curves, this product will have restrictions for use in urbanized or small drainages.

Conclusions

The Corps' end products will provide recommendations for procedures that can be adopted in a future design manual, and tools that will assist SWQIC with modeling, calibration, hydrologic design, floodplain mapping, meeting TMDL program requirements, and ecosystem restoration. Except for a few modifications suggested below, the Corps believes its current Scope of Work (SOW) should remain unchanged.

- The Corps believes it would be beneficial to perform a comparison of MM5's four decades of synthetic rainfall with the new release of the National Weather Services' NOAA 14 Precipitation Depth Duration Frequency Study. If consensus cannot be attained at this time for performing this comparison, then further discussion is recommended at a later date to discuss the specific goals and benefits for such a comparison.

- Currently, there is uncertainty with the method by which project specific BMP's will be hydrologically modeled and designed. This concern exists because the LSPC model that will ultimately result in the establishment of TMDL's is a macro-scale model with a 4 km resolution while BMPs are often designed for areas less than a square mile. In addition, BMPs often have a safety component such as a spillway, which is designed to handle a hydrologic event with a specific, sometimes long, return period. The LSPC model calibration may focus on more frequent events, and thus not be suitable for this purpose. The Corps is willing to assist in the development of a modeling approach that addresses the needs to estimate peak flows, volume, and flow durations at the project scale that is consistent with planned development and implementation of regional TMDLs. This would be an additional item to the Corps' current SOW.

Table of Contents

Page

EXECUTIVE SUMMARY **ES-1**

1. INTRODUCTION **1**

2. CURRENT HYDROLOGIC ANALYSIS PRACTICE **3**

2.1. Introduction *3*

2.2. Current Hydrologic Design Methods *3*

2.3. Comparison of Current Hydrologic Design Methods *5*
2.3.1. Design Precipitation 5
2.3.2. Time of Concentration 8
2.3.3. Runoff Coefficients for Peak Discharge Methods 8
2.3.4. Snowmelt 8
2.3.5. Loss Rates 8
2.3.6. Base Flow 8
2.3.7. Direct runoff computation 9
2.3.8. Channel Routing 9
2.3.9. Storage routing 9

2.4. Conclusions *9*

3. EXISTING METHODS FOR ESTIMATING TMDLS AND REQUIREMENTS FOR BEST MANAGEMENT PRACTICE **10**

3.1. Introduction *10*

3.2. General Principles and Requirements *10*

3.3. Application to Lake Tahoe *11*

4. PROPOSED INVESTIGATIONS IMPORTANT TO DEVELOPING HYDROLOGIC DESIGN CRITERIA AND BEST MANAGEMENT PRACTICE FOR THE LAKE TAHOE BASIN **12**

4.1. Introduction *12*

4.2. Geographic information systems (GIS) – Task 2 .... *13*

4.3. Hydro-Met Data – Task 3.3 .... *13*

4.4. Precipitation Analysis – Task 3.1 .... *14*

4.5. Watershed Model Development – Task 5 .... *14*

4.6. Flood Frequency Analysis – Task 4.1 .... *16*

4.7. Flow-Duration Analysis – Task 4.2 .... *17*

4.8. Low-flow and Drought Analysis – Task 4.3 .... *18*

5. CONCLUSIONS **19**

6. REFERENCES **21**

Appendix A: Regulatory Requirements
Appendix B: Scope of Work

LAKE TAHOE BASIN HYDROLOGY STUDY
TASK 1 ASSESSMENT REPORT:
ANALYZING HYDROLOGIC DESIGN CRITERIA USED IN THE LAKE TAHOE BASIN

LAKE TAHOE, CALIFORNIA AND NEVADA

1. INTRODUCTION

The purpose of this report is to propose to the Storm Water Quality Improvement Committee (SWQIC) for the Lake Tahoe Basin investigations that would establish the requirements for establishing hydrologic design criteria for the Lake Tahoe Basin. The importance of the design criteria stems from both the special nature of the lake and the potential impacts to the lake from non-point source pollution caused by storm water runoff. The special characteristics of the lake are described by the Tahoe Regional Planning Agency (see TRPA, 2002, pg.3-1):

> *The purity of Lake Tahoe and its tributary streams helps make the Tahoe Basin unique. Lake Tahoe is one of the three clearest lakes of its size in the world. Its unusual water quality contributes to the scenic beauty of the Region, yet it depends today upon a fragile balance among soils, vegetation, and man. ....*

This unique quality of the lake, and its fragility, has led to its designation as an "Outstanding National Resource Water," by the U.S. Environmental Protection Agency.

Addressing the potential water quality impacts to the lake is the federally legislated responsibility of TRPA. In addition, potential water quality impacts are regulated by the Lahontan Regional Water Quality Control Board (LRWQCB) and the Nevada Division of Environmental Protection (NDEP) on the California and Nevada portions of Lake Tahoe Basin respectively.

With regard to TRPA, the goal to preserve and ultimately increase water quality of Lake Tahoe is to address the impacts of storm water runoff and the associated non-point source pollution by reducing (see TRPA 2002, pg. 3-1):

> *...loads of sediment and algal nutrients to Lake Tahoe; Meet sediment and nutrient objectives for tributary streams, surface runoff, and sub-surface runoff, and restore 80 percent of the disturbed lands.*

Consequently, there is a great benefit to be gained by having new hydrologic design criteria that not only address the traditional problem of sizing storm water conveyance and delineating the regulatory floodplain; but also, considers the goal of mitigating the impact of non-point source pollution.

In this report, the various requirement for the design criteria will be proposed by examining the problems typically faced in traditional storm water design problems and the non-point source pollution problems identified by TRPA and other stakeholders (federal, state, city and county). The proposed requirements presented are based on a review of the current state of the practice. County, city, state and federal agency guidelines and design manuals, together with regulatory requirements, were reviewed.

The greatest challenge in compiling this report was in integrating the focus of past hydrologic practice with the current requirements needed to address regulatory requirements to protect the environment. In the past, local hydrologic design criteria focused on the standard engineering design problems concerned with controlling the magnitudes of storm water runoff. Such issues as the size of culverts, storage requirements for detention ponds, and establishing floodplain boundaries could be addressed using these design criteria. More recently, best management practice (BMP) requirements to protect receiving water quality focus on completely containing a smaller return interval event (i.e., less frequently occurring) design runoff so that pollutants and sediment are allowed to settle. The design requirements for these smaller return interval events can focus on either volumes or peaks; sometimes referred to respectively as design water quality volumes (WQVs) and water quality floods (WQFs). Although both TRPA and Lahontan suggest using a 20-year, 1-hour design storm, this is not an absolute requirement. BMPs should be designed to meet numeric water quality standards and various water quality design storms should be considered to accomplish this goal.

The traditional hydrologic design criteria have very different objectives. The traditional storm water control design focuses on reducing flows using storage or increasing/provide conveyance to mitigate the impacts of a particular project. In contrast, BMPs attempt to retain flows to allow absorption or sedimentation of pollutants by retaining and/or dispersing a relatively smaller flood for a longer duration than in the traditional floods. The two requirements can conflict when the retention measures are located within the same facility. The need to retain smaller floods for a longer period can increase the overflow risk for the traditional goal of mitigating the effects of a larger flood hydrograph.

However, the specific requirements of retention design only addresses a very specific problem that needs to be addressed by BMPs. BMPs play a role in strategies to protect receiving water quality, stream restoration activities initiated to address wildlife habitat concerns (among other problems), and the general goal of taking a holistic watershed management approach to solving environmental problems. Protection of Lake Tahoe is a prime example of where the overall hydrologic cycle (floods, droughts, flow duration) is important to assessing environmental impacts.

Section 2 provides a review of the current hydrologic criteria described in both county design manuals and in the highway storm runoff design manuals used by Caltrans (the California Highway Department of Transportation) and the Nevada Department of Transportation. Section 3 describes both the current criteria used to establish BMPs and plans for improving these practices for Lake Tahoe. Proposed requirements for modifying the current hydrologic criteria to be consistent with both the traditional storm water runoff design goals and BMPs is discussed in Section 4. Appendix A provides an overview of the regulatory requirements and the administering agencies that have resulted in the current BMPs prescribed for Lake Tahoe.

2. CURRENT HYDROLOGIC ANALYSIS PRACTICE

2.1. Introduction

The purpose of this section is to compare the current hydrologic analysis regulations described in county (see Placer County, 1990, El Dorado County 1995, Washoe County, 1996, and Douglas County, 2001). Section 2.2 summarizes the methods and section 2.3 compares the various methods. Section 2.4 provides some conclusions.

2.2. Current Hydrologic Design Methods

The hydrologic design methods used in current practice address storm water runoff. The goal is to estimate either a peak annual maximum flow or hydrographs associated with some return interval (exceedance probability). The criteria involve the estimates that should be used in the parameters of the method and the level of risk. Noteworthy here is that the level of risk is generally not based on any risk-cost analysis; but rather, is set based on some judgment or historical record of structure overtopping or failure.

The parameters estimated based on criteria fall under the following general categories:

Annual peak discharge analysis

- Runoff formula

  $$Q=CiA$$

  where Q is the peak discharge, C is the runoff coefficient, i is the rainfall depth or intensity, and A is the drainage area to the design point of interest.
- Return interval (exceedance probability)
  The chance that the peak discharge will be equal or exceeded in a particular year. Equated to return interval of rainfall.
- Rainfall
  Rainfall intensity (or depth)-duration-frequency curves are specified for the area. The duration should be related to time for runoff to travel from the most remote part of the watershed to the drainage point of interest. No correction to the depth is made for the size of the drainage area (presumably because the method is used for relatively small drainage areas).
- Runoff coefficient
  Parameter used the fraction of rainfall depth that contributes to the peak discharge. Usually, the runoff coefficient is specified as a function of land use type and some measure of drainage area relief. Coefficient is usually

an area weighted average for mixed drainage area characteristics and does vary with return interval.

- Application
  Peak discharges used for small drainage structure design, such as catch basins and highway culverts.

Hydrograph Analysis

- Watershed representation
  Represented by a conceptual set of elements that represent various responses of the watershed to precipitation input. Basic elements consist of sub-areas, channel and storage elements. The sub-areas are used to represent the transformation of precipitation design storm to a runoff hydrograph, the channel element routes this hydrograph downstream and the storage elements (reservoirs, channel overbank areas, highway culverts and detention basins) simulate the containment/delay of channel hydrographs due to storage. The number and kinds of elements depend on the homogeneity of the watershed and the location of analysis points within the watershed.
- Return interval
  Assumption is that the return interval associated with the design storm is equal to that of the peak discharge of the computed hydrograph assuming somewhat dry soil moisture conditions. Alternatives to this assumption are prevalent, depending on the information available for the watershed.
- Design storm
  A hyetograph developed based on specified depth-duration-frequency curves and depth area relationships (factor to obtain estimated watershed area precipitation from depth-duration-frequency curves). Criteria may be given for both storm temporal and spatial patterns. If snow is possible, then temperature lapse rate or other criteria given to compute proportion of precipitation that falls as snow.
- Antecedent conditions
  Specify the watershed ground “wetness” condition at the beginning of the event, possibly in terms of the initial infiltration, snow pack, base flow, or storage in reservoirs or other impoundments. Should be related to the design storm duration and shape.
- Runoff excess
  Fraction of precipitation that becomes runoff. Complicated by the process involved where this direct runoff is due to surface flow (Horton mechanism) or quick responding subsurface flows (hillslope runoff). Base flow parameter selection and direct precipitation interception may also be involved.
- Base (or subsurface flow)
  Contribution of long-term groundwater storage to runoff hydrograph.
- Runoff routing

Some routing function that transforms the sub-area average runoff excess to a runoff hydrograph.

- Channel routing

  Methods to simulate the conveyance of runoff hydrographs through stream channels. These methods are hydrologic in nature in that backwater (downstream stages) are not accounted for in the routing.
- Storage routing

  Hydrographs are routed based on the storage and outlet characteristics of an impoundment using a "level pool" assumption.
- Applications

  The criteria for estimated parameters are typically given for ungaged analysis (when no historic precipitation and stream flow measurements are available). When available, gage analysis would involve different parameter estimation schemes, which are not generally covered in hydrologic design criteria methods. The application method is limited by the appropriateness of assumptions regarding the design storm for the size of the watershed being modeled.

Table2.1 provides a summary of various applications of these methodologies by counties in the Tahoe Basin, Caltrans and NDOT.

2.3. <u>Comparison of Current Hydrologic Design Methods</u>

The recommended methods and requirements provided in the design manuals described in the previous section from the various agencies are very similar. The differences discussed subsequently are mostly in the details.

2.3.1. Design Precipitation

The design precipitation differs in the depth-duration-frequency (DDF) curves employed and the design storms created from these curves. The DDF curves employed by each agency rely on different sources. In the case of the hydrograph approaches, the temporal patterns for design storms are created differently (based either on local studies, NRCS methods or as described in the HEC-1 model). All the methods assume that the estimated precipitation is uniformly distributed over any sub-basin analyzed, except for Placer County, which assumes an elliptical pattern for their design storm (much like for a Probable Maximum Precipitation). Placer County requires that this storm be centered in such a way as to cause maximum runoff from the watershed for a particular exceedance probability. This is a much more conservative assumption than made by the other agencies.

Table 2.1: Design Manual Hydrologic Design Guidelines

Agency	[1]R_p	[2]D_{storm}	[3]Snow	[4]Loss	[5]Runoff	Base Flow	[7]Channel	[8]Storage	[9]Model	Comments
Placer County peak method	10, 25, 100	nr	nr	constant	unit area	no	nr	nr	unit area peak	direct runoff areas < 200 acres; peak flow a function of unit area discharge, elevation, constant infiltration rate
Placer County hydrograph method	design	T/S	Yes	constant	KW, UH	snowmelt rates plus 1.0 cfs/sq mi	MC, MP, MU	Level Pool (MP)	HEC-1	Design storm function of elevation, area < 200 sq mi, centered to create max runoff, constant loss based on CN, snow covered areas impervious; KW method preferred, UH if it can be shown equivalent to KW, KW subbasin < 1.0 sq mi, MP requires detailed x-sections and backwater profiles, MU when detailed x-section not available.
El Dorado County peak method	design	T_c	nr	Nr	C_i	constant	nr	nr	rational	method constrained T_c < 1hour, area < 100 acres
El Dorado County hydrograph method	design	T/D_a/U	yes	CN	NRCS UH	HEC-1, constant	no	no	TR-55, HEC-1	Temporal precipitation is NRCS type I or Ia depending on elevation; CN for average runoff conditions; UH lag 0.6T_c, T_c computed per TR55

Note: nr = not relevant to method, no = no guidance given
[1]Flood return interval (years), design=indicates return interval computed based on guidance design needs
[2]Design storm temporal T, D_a depth area adjustment, U uniform spatial distribution, spatial S distribution specified, T_c = time of concentration,
[4]Loss rate criteria specified, CN = NRCS curve number,
[5]Runoff transform criteria specified, C_i=rational method runoff coefficient for return period i, UH=unit hydrograph, KW wave
[6]Base Flow, constant = constant discharge, HEC-1 = method described in model
[7]Channel routing criteria specified, no or yes indicates if method specified, MC = Muskingum-Cunge, KW kinematic wave, MP modified puls, MU=Muskingum
[8]Storage routing criteria specified MP = Modified Puls
[9]Watershed model software

Table 2.1: Design Manual Hydrologic Design Guidelines (continued)

Agency	1 R_p	2 D_{storm}	3 Snow	4 Loss	5 Runoff	Base Flow	7 Channel	8 Storage	9 Model	Comments
Washoe County peak method	design	T_c	no	Nr	C_5, C_{100}	nr	nr	nr	rational	"small basins", C_5 used to compute T_c
Washoe County hydrograph method	design	T/D_a/U	no	CN	NRCS UH	no	MC	MP	HEC-1, TR-20	HEC-1 temporal distribution; CN for average runoff conditions; UH lag= 0.6T_c area < 1.0 sq mi, USBR study for western basin for larger areas; MC preferred, KW for small channel reaches
Douglas County, peak method	25, 50, 100	no	no	Nr	no	nr	nr	nr	rational	area < 20 acres
Douglas County, hydrograph method	25, 50, 100	T/D_a/U	no	no	UH, KW	no	no	no	HEC-1, TR-55	Return interval varies by structure; NRCS type II storm, Design storms 6hour duration, TR-55 < 100 acres,

Note: nr = not relevant to method, no = no guidance given
[1]Flood return interval (years), design=indicates return interval computed based on guidance design needs
[2]Design storm temporal T, D_a depth area adjustment, U uniform spatial distribution, spatial S distribution specified, T_c = time of concentration,
[4]Loss rate criteria specified, CN = NRCS curve number,
[5]Runoff transform criteria specified, C_i=rational method runoff coefficient for return period i, UH=unit hydrograph, KW wave, MU=Muskingum
[6]Base Flow, constant = constant discharge, HEC-1 = method described in model
[7]Channel routing criteria specified, no or yes indicates if method specified, MC = Muskingum-Cunge, KW kinematic wave, MP modified puls
[8]Storage routing criteria specified MP = Modified Puls
[9]Watershed model software

2.3.2. Time of Concentration

Time of concentration (T_c) estimates are important to both the determination of the duration used for estimating the intensity used in the peak discharge methods; and in the case of hydrograph methods, the shape of the unit hydrograph and the duration of a model simulation. The differences between the computations of T_c among the various methods results from the various studies used to relate it to roughness, overland and channel flow lengths. Estimates of roughness coefficients used differ among the methods.

2.3.3. Runoff Coefficients for Peak Discharge Methods

Runoff coefficients, usually employed for the rational method, represent a single parameter that is typically used to capture the effect of losses and conveyance on peak discharge. Each agency has its own estimates of these coefficients, and various limitations on when this coefficient method can be applied. The limitations require that the computed peak discharge result from direct runoff and be limited to relatively small drainage areas (these two requirements are related in that the larger the drainage area the likelihood increases that storage of some kind will not be well captured by the runoff coefficient).

2.3.4. Snowmelt

Placer County specifies snowmelt rates to be used as a function of return interval and elevation. El Dorado County notes that snowmelt can make a significant contribution to runoff. They suggest (El Dorado County, 1995, pg. 2-9):

> *To account for this, an appropriate adjustment to design storm precipitation should be made. The engineer should refer to appropriate publication of the Corps of Engineers, the SCS, and the World Meteorological Organization, and should coordinate with the County to select this adjustment.*

2.3.5. Loss Rates

The loss rates methods described were all based on the NRCS curve number (CN). Washoe and El Dorado County specify the average antecedent moisture conditions (AMC II) when selecting the CN. Placer County uses the CN approach to compute a constant loss rate, that assumes no initial loss rates (a wet antecedent runoff condition, AMC III).

2.3.6. Base Flow

Placer County provides specific values for base flow and recommends that the base flow can incorporate snowmelt-based runoff. El Dorado County allows either a constant value or estimates based on algorithms provided in the HEC-1 computer model. Values are to be determined by the analyst.

2.3.7. Direct runoff computation

Unit hydrograph and kinematic wave algorithms are specified. El Dorado and Washoe County require the use of the NRCS dimensionless unit hydrograph. The difference between the recommendations center on how the unit hydrograph lag and peaking coefficient are computed. A major difference exists with the Placer County recommendation for use of the kinematic wave rather than unit hydrographs. Although the county notes that a unit hydrograph can be used if it produces results consistent with the kinematic wave method. This correspondence is not likely given the linear response nature of the unit hydrograph and non-linear nature of the kinematic wave response.

2.3.8. Channel Routing

Placer County provides guidelines for using Muskingum Cunge, Modified Puls-backwater profile combination, and the Muskingum methods. The Muskingum method is allowed when little cross section information is available. This is a bit curious in that the information available to estimate Muskingum method parameters could also be used to produce parameters for the Muskingum-Cunge method, which is a more well founded method.

El Dorado County recommends the use of the Muskingum-Cunge method, but allows for use of the Kinematic Wave for short channel reaches. This is also curious since the parameters for one can be used interchangeably with the other, and Muskingum-Cunge is a more generally applicable method (being appropriate anywhere that the Kinematic Wave method is appropriate).

2.3.9. Storage routing

Placer County recommends the use of level pool (Modified Puls) for storage routing. This is a standard approach commonly accepted.

2.4. Conclusions

The methods recommended by the agencies and transportation departments are very similar. However, the parameter estimation recommendations differ in terms of source of information and degree of conservatism. Placer County takes a very conservative approach to computing runoff. This conservatism comes from both the design storm and loss rates used. The design storm has a designated spatial pattern, which is to be centered to provide maximum runoff, much like in probable maximum flood (PMF) studies. The goals of developing maximum floods, such as in developing the PMF, are not necessarily required for estimating the 1% chance flood. The loss rates are also conservative in that no initial loss is used (basically a wet antecedent condition). In comparison, El Dorado and Washoe Counties assume average antecedent wetness conditions when estimating loss rates.

Useful investigations would involve comparing precipitation depth-duration-frequency curves, parameter estimation techniques for direct runoff and channel routing, assumptions regarding design storms, and the computation of loss rates. Recommendations could then be made regarding the development of HDC, which would promote consistent runoff estimates within the study area.

3. EXISTING METHODS FOR ESTIMATING TMDLS AND REQUIREMENTS FOR BEST MANAGEMENT PRACTICE

3.1. Introduction

Section 303(d) of the federal Clean Water Act requires states to identify surface water bodies that do not meet and are not expected to meet water quality standards. Such water bodies are then prioritized for the development of Total Maximum Daily Loads (TMDLs). TMDLs are strategies to ensure the attainment of water quality objectives. Best management practices (BMPs) are developed to limit discharges to meet these TMDL constraints.

The purpose of this section is to review the hydrologic analysis methods and criteria that are applied as part of BMPs in general by regulatory bodies in Californian and Nevada; and the special requirements developed by TRPA for the Lake Tahoe Basin.

In Section 3.2, the general principles used to estimate TMDLs and the requirements for BMPs related to these estimates are discussed. How these principles have been applied to the Lake Tahoe basin to estimate TMDLs and develop BMPs is described in Section 3.3. It should reiterated that an original task of the Corps is to “review ongoing studies with respect to BMP and TMDL studies in the project area.”

3.2. General Principles and Requirements

The U.S. Environmental Protection Agency (USEPA) (Guidance for Water Quality-Based Approach to Pollution Control: The TMDL process, http://www.epa.gov/owow/tmdl/decisions/) provides a description of the TMDL approach to meeting water quality objectives. The objectives are developed based on the beneficial uses identified for a water body. BMPs are applied to control non-point source runoff to meet the limits set by the estimated TMDLs.

The Lahontan Regional Water Quality Control Board (LRWQCB) and the Nevada Division of Environmental Protection (NDEP) have been designated by the USEPA to administer regulations with regard to the Clean Water Act (CWA), including the estimation of TMDLs. According to NDEP (see, http://ndep.nv.gov/bwqp/tmdl.htm):

> *When a TMDL is developed, the draft is noticed for public comment. After making any appropriate modifications in response to public comment, the TMDL is sent to the United States Environmental Protection Agency for approval. Once approved, the TMDL is implemented through existing National Pollutant Discharge Elimination System (NPDES) permits for point source discharges and voluntary nonpoint source control programs, to achieve the necessary pollutant reductions.*

BMPs are developed for various activities (agriculture, forestry, urban development, etc.) with the intent of meeting the constraints imposed by the estimated TMDLs. Hopefully, BMPs limiting discharges to the estimated TMDLs will meet the water quality objectives. However, following a BMP does not necessarily mean that water quality objectives will be met. Continued monitoring is necessary to assess the effectiveness of a non-point source pollution control strategy.

3.3. Application to Lake Tahoe

Special consideration has been given to the establishment of water quality objectives for Lake Tahoe because of its designation as an Outstanding National Resource Water (under Section 208 of the CWA, water bodies can be given special designations, other examples being Wild and Scenic River, Sole-Source Aquifer and Water Quality Limited Segment). Because of this unique designation, the Tahoe Regional Planning Agency (TRPA) was established by Federal legislation to be responsible for administering provisions with regard to Section 208 of the CWA for the Lake Tahoe Basin.The water quality objectives have been determined based on a water quality threshold study (see TRPA, 2002).

TRPA has established threshold concentration limits of designated runoff constituents, which should be controlled by the design of BMPs for the Lake. These thresholds (see TRPA, 2002, pg.; 3-3) include:

> *..... along with other environmental values and standards, identify important issues relating to water quality in the Tahoe Region. Water quality policies generally fall into two areas:*
>
> > *1. Reducing loads of sediments and algal nutrients to Lake Tahoe; and*
> > *2. Controlling other water pollutants affecting, or potentially affecting, water quality.*
>
> *The strategies for protecting water quality are guided by the thresholds that set numerical and management standards within the pelagic and littoral zones of Lake Tahoe, its tributary streams, and for surface runoff and groundwater.*

Furthermore (TRPA, 2002, pg. 3-6):

> *All of the water quality thresholds include numerical standards, most of which were established by review of monitoring data during the late 1960s/early 1970s. These standards are based on the assumption that Lake conditions during this time period are the end-goal, and that they should be attainable through implementation of compliance measures. In addition to these standards, specific indicator units introduced above, and interim targets have also been established.*

The BMPs used to address this non-point source storm water runoff problem by using the following control program (LRWQCB, 1994, pg 5-3):

- *Large-scale remedial erosion and drainage control (Capital Improvements Program) and SEZ* [note: Stream Environmental Zone] *restoration projects.*

- *Installation and maintenance of onsite erosion and surface runoff (storm water) control measures in connection with all new and existing development.*

- *Controls on nonpoint source discharges from new development, including new subdivisions, new development in SEZs, new development with excess impervious surface coverage, and new development not offset by remedial measures.*

- *Controls on discharges related to other activities including timber harvest, livestock confinement and grazing, and recreational facilities (including golf courses, dredging, and shorezone construction to support water-related recreational activities).*

TRPA's Handbook of Best Management Practices (1988) is mostly concerned with the control of the above storm water runoff problems and associated erosion. In terms of hydrologic criteria, the water quality volume (WQV) specified for the practice is that **the 20-year, 1-hour "design storm" be used for storm water control facilities (see LRWQCB, 1994, section 5-6)**. Pursuant to subsection 25.5.A of the TRPA Code of Ordinances, all property owners in the Tahoe Basin are required to install infiltration facilities designed to accommodate the volume of runoff from a six-hour storm with a two-year recurrence probability (or a twenty year/one hour storm, which is approximately one inch of precipitation in an hour). Currently NDOT, Caltrans, and the counties and city currently recognize this WQV as the quantitative requirement for storm water treatment design in the Lake Tahoe Basin.

4. PROPOSED INVESTIGATIONS IMPORTANT TO DEVELOPING HYDROLOGIC DESIGN CRITERIA AND BEST MANAGEMENT PRACTICE FOR THE LAKE TAHOE BASIN

4.1. Introduction

Existing hydrologic design criteria (HDC) and best management practice (BMP) requirements address different regulatory issues. Existing HDC, as described in county design manuals, typically provide guidelines for quantifying flood event characteristics, such as 2-year (50% chance annual exceedance probability) peak flow or the 100-year (1% exceedance probability) design hydrograph. These flood measures are used to establish the size of control structures, drainage capacity or regulatory floodplains.In contrast, BMP requirements currently address measures needed to meet the quantitative requirement indicated previously from non-point sources (i.e., runoff the 20-year, 1-hour event or 1-inch across all impervious surfaces).

The comparison of the various county and transportation agency methods described in Section 3 revealed that there is a great deal of similarity between the methods recommended for computing storm event runoff. However, differences exist in the precipitation depth-duration-frequency curves, the parameter estimation techniques used to obtain routing parameters, snowmelt estimates, time of concentration values and loss rates used in these methods. The degree of conservatism incorporated within the parameter estimation schemes varies greatly. An important aspect of any proposed investigations would be to make recommendations on how to obtain both best and consistent method and parameter estimation schemes within recommendations for HDC. Parameter estimation schemes should not be confused with actual parameter values as this is not in the Corps' Scope. Section 4.5 covers this topic in more detail. The Corps will be developing products useful for new HDC in Lake Tahoe, but not a design manual.

The opportunity exists to develop new realistic HDC that are consistent with both the need for standard storm water runoff rate and volume computations, while at the same time providing updated information for storm water runoff quality control designs.

The following areas important to developing HDC will be discussed in subsequent sections of the Corps SOW provided in Appendix B:

- Geographic information systems, (Task 2)
- Hydro-meteorologic data, (Task 3.3)
- Precipitation analysis, (Task 3.1)
- Watershed model development, (Task 5)
- Flood frequency analysis, (Task 4.1)
- Low-flow frequency and drought analysis, (Task 4.2)
- Flow-duration analysis (Task 4.3)

4.2. Geographic information systems (GIS) – Task 2

An extensive effort has already been made to develop GIS layers for the Lake Tahoe Basin. This information needs to be reviewed to determine what additional information can be provided. The U.S. Army Corps' Cold Region Research and Engineering Laboratory (CRREL) has an extensive inventory of remotely sensed data that might be useful to the TMDL study. At the very least, the data available on snow water equivalent will be used to establish antecedent conditions for simulating design precipitation events (Task 3.4 of Corps SOW). GIS information gathered by the Corps as part of Task 2 of the SOW will be provided to SWQIC.

4.3. Hydro-Met Data – Task 3.3

As mentioned in the previous section, CRREL has a significant period of record of remotely sensed data that can be used to estimate snow water equivalent for the Lake Tahoe Basin. This information can be used to produce snow water equivalent values useful for storm runoff modeling. Snow water equivalent maps and text on their intended use will be developed for the entire Lake Tahoe basin as part of Task 3 of the SOW. It is envisioned that these maps will be integrated into the new design manual for the region (future scope of work).

4.4. Precipitation Analysis – Task 3.1

A limited amount of gage information is available for the basin. Efforts are under way to use a physically based atmospheric model, MM5, to estimate period of record information at a relatively small grid-scale for the basin. An alternative approach was used to obtain this variation in the recently published depth-duration frequency curve study (NOAA 14 Depth Duration Frequency Maps, 2003) by the National Weather Service for much of the southwestern United States. The National Weather Service estimates are most likely to be used region wide; and more specifically, in design criteria for the Lake Tahoe Basin. As part of Task 3 of the SOW, the Corps will review the NOAA14 Study and give recommendations for its use in the future design manual. A comparison of the depth-duration frequency estimates resulting from the National Weather Service and the MM5 precipitation values would be useful in development of hydrologic design criteria. This precipitation comparison, agreed upon by SWQIC will be included in a Corps SOW technical document (made part of Task 3.1).

The Corps will also develop a set of frequency based design storms with temporal and spatial distribution. This will be accompanied by corresponding antecedent soil and snowpack conditions. This product can be integrated into the new design manual (Task 3.4).

4.5. Watershed Model Development – Task 5

As noted in Section 3, the models used to estimate storm water runoff by the counties, city and transportation agencies are very similar. However, recommendations could be made to promote consistency in the drainage designs within the study area based on studies of the various parameter estimation techniques for computing routing, loss rate and snowmelt parameters. This work will be performed in Task 5 of the SOW. Recommendations on rainfall-runoff modeling techniques to adopt in the new design manual will be provided, keeping in mind that members of the SWQIC may want to integrate some procedures into the hydrologic design of BMPs. At the time this report was written, it is not clear within the SWQIC how BMPs will be hydrologically designed, especially in light of the fact that LRWQCB is developing its own precipitation and hydrology to meet the goal of establishing regulatory TMDLs. Resolving this issue is outside of the Corps' current SOW..

BMPs are often located in urbanized areas and have drainages of less than 100 acres. The regression equations the Corps will develop for high flow frequency, low-flow frequency, and flow-duration curves will not be applicable to these areas due to the nature of the regional stream gages upon which the analysis is based. For this situation, the Rational Method or rainfall-runoff modeling will have to be used for the hydrologic design of BMPs. A small-scale LSPC model is also a possibility. It is possible that that the current work being performed by LRWQCB in developing a LSPC water quality model might provide additional information on soil loss rates and percent impervious needed to model urban areas in the Tahoe basin. The exact method in which individual BMPs will be designed has not yet been determined as of the writing of this report.

For Task 5, recommendations will be given for the most appropriate techniques to determine runoff hydrographs important for traditional flood protection and drainage design.

These methods may also be useful for applications to best management practice (this will depend on future criteria developed in the Lake Tahoe basin relating water quality to total maximum daily loads). The focus of the recommendations will be to develop the best methods that can be used Basin-wide to:

1. Determine design precipitation;
2. Transform precipitation to direct flow volumes by estimating precipitation loss rates and factoring in subsurface flow contributions; and
3. Route these volumes to the watershed outlet or design point using channel flood routing techniques;

The recommendations will also utilize the current investigation into the appropriate design storms and antecedent moisture/snowpack conditions for the Lake Tahoe Basin. The goal of the recommendations is to identify the most appropriate methods for the Lake Tahoe basin and how the parameters can be estimated (parameter estimation scheme, not actual values) given the data available (gaged vs. ungaged), the type of watershed being investigated (urban vs. natural) and the problem being considered (e.g., culvert design for small drainage areas versus retention basin design for larger areas). The recommendations will provide a useful guide for estimating parameters for the methods in an application, and in providing consistent estimates across the Basin. Further clarification as to the end products SWQIC will receive is provided below:

1. Loss Rate Method: The Corps will recommend a soil loss rate method for rainfall-runoff modeling such as the SCS Curve Number or Constant/Initial Loss Method. Antecedent soil loss conditions (wet, normal, dry) will be derived by the Corps in Task 3.3. The Corps will **not** provide actual loss rate values or Curve Number Matrices. This level of detail will need to be addressed in the design manual development phase which is not part of the Corps' SOW.

2. Base Flow: The Corps will examine base flow. If base flow appears to be significant, a recommendation will be made on a common procedure for its derivation. Derivation of actual base flow values for each creek is not in the Corps' SOW.

3. Snowmelt Modeling: Antecedent snow water equivalent maps for the Lake Tahoe Basin will be developed for SWQIC as part of Task 3.3. In Task 5, the Corps will recommend procedures for modeling snowpack effects for a design storm.

4. Direct Runoff Computation: Direct runoff computation is accomplished in a rainfall runoff model using a unit hydrograph procedure or the kinematic wave algorithm. The method used in various agencies' design manuals varies. The Corps will recommend a procedure for adoption in the future regional design manual. This would include recommendations on computing Time of Concentration (Tc) or Lag as needed. Derivation of specific parameters used to compute Tc such as roughness coefficients for specific locations is **not** included in the Corps' SOW.

5. Channel routing methods currently utilized in the Basin include Muskingum, Muskingum Cunge, Modified Puls-backwater profile combination, and Kinematic Wave: The Corps will make recommendations to standardize the procedure used in the new design manual. Derivations of specific hydraulic parameters like weir coefficients or Manning *n* values are **not** included in the Corps' SOW.

4.6. Flood Frequency Analysis – Task 4.1

Flood flow frequency analysis is directly relevant to storm water design issues, providing the discharge for an annual return interval or the elevation of the regulatory floodplain. This analysis has importance also for estimating TMDLs, providing calibration/verification information for the LSPC model, and is needed for comparing the regulatory floodplains with stream environmental zones (SEZs). Suggested methods for estimating TMDLs (see NDEP, 2003 and recent suggestions by the USDA National Sedimentation Laboratory) have integrated frequency estimates obtained from annual flow frequency curves and flow duration curves with the sediment load associates with the flow quantile (the flow for a particular frequency).

The development of the LSPC model requires both calibration to existing gage data and verification of the calibrated model predictions. Flood flow-frequency estimates can be obtained at ungaged locations from regional relationships. The Corps of Engineers proposes to develop these regional relationships as part of its analysis for the SWQIC Committee (Task 4.1 of Corps SOW).

These regional estimates could be used for verification or possibly calibration of the period of record model simulations at ungaged locations for other modeling efforts (i.e., LSPC). This would be done by comparing the flood flow-frequency curves estimated from the period of record simulations (LSPC model) and the Corps' regional estimates. A significant difference between the two methods does not necessarily indicate that one method is wrong. Both approaches provide an estimation of the true flow regime. This comparison has the potential to improve estimates from both methods over a range of flows and watershed conditions, and to promote consistency in various types of hydrologic analyses. If SWQIC is interested, this comparison could be performed as a separate scope by the Corps or another qualified entity.

SEZs play an important role in BMP strategies as "natural" treatment facilities. The boundaries of the SEZs do not necessarily correspond to the regulatory 100-year floodplain. Development outside of this floodplain may interfere with strategies to use SEZs. Consequently, updated flow-frequency estimates will be important in defining the regulatory floodplain boundaries for comparison with SEZ boundaries.

Finally, a general use of flood flow-frequency curves is to categorize a pre-project condition. For example, the peak annual flood flow-frequency curve characterizes the flood runoff characteristics prior to a construction project. Traditionally, any urban development needs to mitigate impacts in the storm water drainage design (typically using a detention pond) by preserving the flood flow-frequency curve. This is a no-impact principle, which is also relevant to BMPs. A standard principle is that the water quality of runoff from a site should not be impacted by any actions taken at that site. The flood flow-frequency curve is an essential piece of information that can be used in a BMP to ensure a no-harm design.

Flood flow frequencies studies might involve: 1) selecting a flood flow-frequency analysis procedure by performing a comparative study of the Bulletin 17B guidelines (the guidelines followed by federal agencies) and other well known estimation procedures; 2) examine if record augmentation at shorter record stations is possible using correlation with longer record stations; 3) perform a regional annual maximum flood flow frequency analysis; and, 4) develop regional regressions between basin characteristics and flood quantiles applicable to ungaged areas.

Regional regression equations for flood flow frequency will be an important tool to SWQIC in the envisioned future method of hydrologic design at Lake Tahoe. Only 25% of the major creeks in the basin are gaged. Regional regression equations can provide useful data for ungaged locations. Uses include delineating floodplains and calibrating and/or validating event-driven rainfall runoff models in non-urban areas. This product will be derived as part of Task 4 of the SOW.

Limitations: The regional flow-frequency regression equations for peak and volume will be developed from an analysis of stream gages both within and outside of the Lake Tahoe Basin. These gages are usually located in mostly undeveloped watersheds. The Corps will determine whether the watershed estimation parameters used (such as slope or mean annual rainfall) provide adequate correlation and whether the equations can reasonably reproduce flood flow-frequency curves for gaged locations. The product will have limitations. It will **not** be applicable to watersheds less than a specific size (perhaps smaller than a couple hundred acres), and for areas in which a significant percent of the “contributing” watershed is urbanized. Given the above limitations, these regressions will still be quite useful. For example, smaller sub-basins can be aggregated together in a larger rainfall-runoff model thus allowing comparison of results with the regressions (peak and volume).

4.7. Flow-Duration Analysis – Task 4.2

Flow-duration analysis is particularly applicable to water quality BMP and ecological restoration design, and may be applicable to project impact analysis. The development of these relationships can be done using the data compiled for the flood flow frequency analysis.

Tracy and Rost (2003) perform interesting initial research into developing flow-duration relationships. More could be done to investigate different models for the at-site flow duration curve estimates and the regression models used to regionalize the estimates.

Flow-duration curves are normally computed statistically from period of record daily flows at a gaged site. Unlike flood flow-frequency curves, which estimate the probability of some extreme event (high or low flows), flow-duration curves are based on the whole period of record and provide an accurate picture of the typical flow regime over time for a given location. A flow duration curve, when “linked” or “integrated” with a pre-determined “flow versus sediment loading relationship”, could possibly be useful by the Corps’ partners for the following: 1) as a possible method for computing a regulatory TMDL, 2) as a method of predicting the future risk of sediment loading into the lake from a particular watershed, 3) calibrating and/or providing independent verification of the flow regime computed in a continuous simulation rainfall-runoff model such as LSPC, and 4) as a tool to analyze the ability of an individual BMP to reduce sediment load. The LSPC model, when calibrated, could provide the necessary link between runoff and sediment yield for a given area in the Lake Tahoe Basin. The sediment loading factor will vary with location. Watershed characteristics such as snowpack, vegetation cover, disturbance, and land-use effect loading potential.

Another use of flow-duration curves is for riverine ecosystem restoration studies. These curves help biologists determine whether target species will survive after restoration features are implemented. Given the many potential uses of flow-duration curves, the Corps, as part of its proposed Scope of Work, will attempt to develop regional equations for the prediction of flow-duration curves for ungaged areas in the Lake Tahoe region. The future uses of this product will be determined by the organizations that comprise the SWQIC (another tool for their use). This product will be derived as part of Task 4 of the SOW.

<u>Limitations:</u> The regional flow-duration curves the Corps proposes to develop will be analyzed using stream gages both within and outside of the Lake Tahoe Basin (regionalized). The Corps will determine whether the estimation parameters used provide adequate correlation and whether the equations can reasonably reproduce flow-duration curves for gaged locations. The product will have limitations. It will not be useful for watersheds less than a specific size (perhaps smaller than a couple hundred acres), and it will not be applicable for areas in which a significant percent of the "contributing" watershed is urbanized. Initially, the Corps will only produce equations for creating annual flow-duration curves. However, seasonal flow duration curves could be developed economically at a later date. Given the above, however, the regionally derived flow-duration curves for ungaged basins will be a useful tool. For example, they can be used to calibrate one or a series of non-urbanized subbasins in a larger scale continuous simulation model.

4.8. Low-flow and Drought Analysis – Task 4.3

Low-flow and drought analysis, like flow duration analysis, is not something typically found in a design manual. . However, it can be accomplished with the data that will be available as part of a flood frequency investigation.

The relevance to storm water runoff control using BMPs is not completely obvious either. However, Pahl (2002b) points out:

> *When people are first exposed to the TMDL concept, they tend to think in terms of loads when contemplating our water quality problems. However, there are other culprits that either cause impairment or at least contribute to the problem. For example, the water from the major streams in Nevada is utilized for a variety of consumptive uses, such as irrigation, drinking water, etc. These uses can lead to lower flows during certain times of the year thereby interfering with the river's ability to assimilate loads and support other beneficial uses. However, NDEP has no ability to regulate flows for*

compliance with water quality standards. According to the Clean Water Act (Water Environment Federation, 1997),

> *"[I]t is the policy of Congress that the authority of each State to allocate quantities of water within its jurisdiction shall not be superseded, abrogated or otherwise impaired by this chapter. It is further the policy of Congress that nothing in this chapter shall be construed to supersede or abrogate rights to quantities of water which have been established by any State."*

Nevada is the driest state in the nation. When beneficial uses were first recognized in the state regulations (1970s), some of these uses were based upon desired future conditions and not actual uses at the time. With much of the water diverted from the rivers for beneficial uses such as irrigation and drinking water, some of the other beneficial uses, such as propagation of aquatic life, cannot be sustained during parts of the irrigation season. (see Pahl 2002)

Consequently, low-flow and drought issues may not enter directly into BMP considerations, but it may be important in evaluating if an overall Basin plan can meet water quality objectives for all potential hydrologic conditions. Characterizing, the risk associated with low-flows or droughts is probably important for assessing if water supply constraints will prevent meeting water quality objectives.

Low-flow frequency is an attempt to assign probability to annual minimum flows. The 10-year, 7-day low is often used in water quality studies. It is the lowest, continuous 7-day averaged flow value that has a 1/10 chance of not being exceeded in any given year. Predicting low-flow frequency for ungaged areas is difficult. Each watershed has its own characteristic low-flow. Some of these include localized groundwater recharge into the river, small irrigation or water supply diversions which are often not documented, and root zone uptake from riparian trees and vegetation. If successful, the product will be useful for water quality studies and biological assessments. This product will derived as part of Task 4 of the SOW.

Limitations: Regional low-flow frequency becomes increasingly difficult for shorter durations. Predicting a 1-day low flow is more difficult than a 30-day low flow. After the analysis is completed, only one or more equations may be developed for specific durations. Difficulty in performing the analysis and funding constraints will determine what durations, if any, can be predicted with reasonable confidence.

5. CONCLUSIONS

The Corps of Engineers undertook an extensive review of the issues that effect deriving hydrometeorological products that would meet the needs and goals of the SWQIC Committee including the protection of Lake Tahoe's water quality. Hydrologic design manuals, published documents, web site content, and other available information published by numerous federal, county, state, and local government agencies in the region were reviewed. Interviews were conducted with key personnel, scientists, and engineers in most agencies. An overview of ongoing scientific research in the Basin was undertaken including interviews with research scientists. An effort was made to review recent studies or research papers pertinent to this study including regional regression studies for flow frequency and flow-duration, TMDL analysis and determination, and BMP design. The primary conclusion of the Corps is that its proposed Scope of Work dated 17 September 2003 is sound and should serve as an appropriate framework for the analyses it will perform for SWQIC. One other conclusion is noted below.

- The Corps suggests performing a comparison of the MM5 four decades of synthetic rainfall data with the NOAA 14 depth-duration frequency study. These two approaches represent an estimation of the precipitation regime in the Lake Tahoe Basin and it might be useful to know if they differ significantly. A comparison can be made by analyzing the 40-year precipitation period of record simulated by MM5 to obtain a depth-duration frequency (DDF) curve at any particular location in the Basin. The DDF curves from the MM5 simulated precipitation can be compared to NOAA 14 DDF curves. This comparison is likely to be important for Basin researchers, regulatory agency personnel and implementing personnel alike. That is, TMDLs might be computed by integrating a flow frequency relationship with a flow versus load relationship to obtain a permissible average or expected future pollutant loading. At a small scale, the precipitation DDF curve would be used (with the rational method for example) to obtain the flow frequency curve. Additionally, integrated water quality and flood peak reduction design, such as in the design of a retention basin used to control both high and low flows, will depend in many cases on the use of a precipitation DDF curve. Therefore, it is important to know how the different data sets of precipitation relate as they will both likely be used on any given water quality improvement project being designed in the Basin. An initial comparison of the precipitation data sets was made and presented at the September 15, 2004 SWQIC meeting. A technical write-up of this comparison will be provided as a part of Task 3 (Corp SOW). Additional comparisons of TMDL and HDC data will likely not occur until after final products are released from both studies.

- Currently, there is uncertainty with the method by which project specific BMP's will be hydrologically modeled and designed. This concern exists because the LSPC model that will ultimately result in the establishment of TMDL's is a macro-scale model with a 4 km resolution while BMPs are often designed for areas less than a square mile. In addition, BMPs often have a safety component such as a spillway, which is designed to handle a hydrologic event with a specific, sometimes long, return period. The LSPC model calibration may focus on more frequent events, and thus not be suitable for this purpose. The Corps is willing to assist in the development of a modeling approach that addresses the needs to estimate peak flows, volume, and flow durations at the project scale that is consistent with planned development and implementation of regional TMDLs. This would be an additional item to the Corps' current SOW.

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APPENDIX A

Subject: Regulatory Requirements

The regulatory requirements for water quality in the Lake Tahoe Basin seem to be primarily related to the Federal Clean Water Act (CWA, sections 208, 401,402), Federal Safe Water Drinking Act (SWDA), and the California State Porter-Cologne Water Quality Control Act 9. The responsibility for interpreting these laws and enforcing the related regulations is not entirely clear at this point, but the following attempts to describe the main players.

In general, it seems, that the Tahoe Regional Planning Authority has a significant responsibility with regard to setting regulatory standards and coordinating basin planning to protect water quality. They may also be the lead agency in enforcing regulations related to CWA and SWDA. Lahontan Division of the California State Regional Water Quality Control Board is responsible for regulations relating to CWA and SWDA in California (as well as state water quality requirements) and the Nevada Department of Environmental Protection in Nevada. A description of these agencies and other players follows.

The Tahoe Regional Planning Authority (see Web page: www.trpa.org)

> The governors and lawmakers in California and Nevada approved a bi-state **Compact** that created a regional planning agency to oversee development at Lake Tahoe. In 1969, the United States Congress ratified the agreement and created the Tahoe Regional Planning Agency. The **Compact** as revised in 1980, gave TRPA authority to adopt environmental quality standards, called thresholds, and to enforce ordinances designed to achieve the thresholds. The TRPA Governing Board adopted the thresholds in l982. The initial thresholds were challenged, and based on a consensus of various stakeholders; the final thresholds were adopted as described in the **1987 regional plan**.
>
> The Regional Plan is a progressive plan. Because TRPA is exploring new territory in the field of environmental planning, the Regional Plan will continue to mature as we learn more about how man impacts the environment. The Code of Ordinances is the most visible of several documents which make up the Regional Plan. The Code regulates, among other things, land use, density, rate of growth, land coverage, excavation and scenic impacts.
>
> Other documents in the Regional Plan include the Goals and Policies, the Water Quality Management Plan (the "208" plan), the Plan Area Statements and the Scenic Quality Improvement Plan.

Lahontan Regional Water Quality Control Board (State of California) and Nevada Department of Environment Protection

> The California Environmental Protection Agency (CalEPA) and Nevada Department of Conservation and Natural Resources (NDCNR) oversee the implementation of state and federal regulations that pertain to water quality including Sections 208, 401 and 402

of the federal Clean Water Act. The primary responsibility for the protection of water quality in project vicinity rests with the Lahontan Regional Board under the CalEPA and Nevada Department of Environmental Protection under NDCNR.

El Dorado County

Chapter 7 in the El Dorado County General Plan (Conservation and open space) includes goals for Conservation and Protection of Water Resources. Goal 7.3 is to "Conserve, enhance, and manage water resources and protect their quality from degradation.

Caltrans (State of California)

The State of California Transportation Department (CALTRANS) interpretation and implementation of water quality standards is important because of their responsibility to control highway drainage. They are generally concerned with federal regulations for controlling discharges of pollutants from municipal separate sewer systems, construction sites, and industrial activities, under the NPDES permit process described in 1987 amendments to the Clean Water Act (CWA), and the subsequent 1990 promulgation of federal storm water regulations issued by the U.S. Environmental Protection Agency (USEPA). The USEPA regulations require municipal and industrial storm water discharges to comply with an NPDES permit. In California, the USEPA delegated authority to issue NPDES permits to the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCBS)

Nevada Department of Transportation (NDOT)

NDOT establishes storm water control practices based on permits from the Nevada Department of Environmental Protection.

APPENDIX B – Preliminary Scope of Work

Product Deliverables **17 Sep 03**

Developing Lake Tahoe Hydrologic Standards Criteria for a Design Manual

Sacramento District, U.S. Army Corps of Engineers

Task	Description	**Deliverable**
1.0	**INITIAL ASSESSMENT**	**Summary report describing state of the practice, ongoing studies and consensus on needed criteria**
1.1.	Assess existing practice and ongoing studies	
1.2.	Define Criteria/Methods Selection Process, develop stakeholder consensus	
2.0	**DATABASE**	Hydro-meteorological time series and GIS data base
3.0	**PRECIPITATION/METEOROLOGIC EVALUATION AND ANALYSIS**	Report providing precipitation depth-duration frequency curves, snow-water equivalent mapping, and frequency based design storms with corresponding initial conditions
3.1.	Review current NWS depth-duration frequency study	
3.2.	Augment current depth-duration frequency study (as needed)	
3.3.	Snow water equivalent mapping/frequency analysis	
3.4.	Develop design storms/antecedent conditions	
4.0	**FLOW FREQUENCY ANALYSIS**	Report describing frequency curves for low and high flows, flow-duration curves, and regional regression equations for each flow type
4.1.	At-site Flood (high flow) frequency analysis	
4.2.	At-site low-flow frequency analysis	
4.3.	At-site flow-duration analysis	
4.4.	Regional regressions for high flow frequency curves, low-flow frequency curves and flow-duration curves useful for ungaged watershed analysis	
5.0	**RECOMMENDED PRECIPITATION-RUNOFF MODELING APPROACHES**	Report describing recommended modeling approaches
6.0	**SUMMARY REPORT**	Summary report

Budget and Schedule Proposal 17 Sep 03

Developing Lake Tahoe Hydrologic Standards Criteria for a Design Manual
Sacramento District, U.S. Army Corps of Engineers

Task	Description	**Budget**	**Schedule**
1	**INITIAL ASSESSMENT**	**39200**	15 Sep – 15 Dec 03
1.1.	Assess existing practice and ongoing studies	-	
1.2.	Define Criteria/Methods Selection Process, Develop Stakeholder Consensus	-	
2	**DATA BASE**	**31450**	**15 Nov 03 – 30 Jan 04**
3	**PRECIPITATION/METEOROLOGIC EVALUATION AND ANALYSIS**	**65150**	**15 Dec 03 – 15 Feb 04**
3.1.	Review current NWS depth-duration frequency study	-	
3.2.	Augment current depth-duration frequency study (as needed)	-	
3.3.	Snow water equivalent mapping/frequency analysis	-	
3.4.	Develop design storms/antecedent conditions	-	
4	**FLOW FREQUENCY ANALYSIS**	**99000**	**15 Feb 04 – 31 JUL 04**
4.1.	At-site Flood (high flow) frequency analysis	-	
4.2.	At-site low-flow frequency analysis	-	
4.3.	At-site flow-duration analysis	-	
4.4.	Regional regressions for high flow frequency curves, low-flow frequency curves and flow-duration curves useful for ungaged watershed analysis	-	
5	**RECOMMEND PRECIPITATION-RUNOFF MODELING APPROACHES**	**19550**	**31 Jul 04 – 31 Aug 04**
6	**SUMMARY REPORT**	**20550**	**15 Jul 04 – 30 Sep 04**
		SUBTOTAL = 274,900	
	Contingency (10%)	TOTAL = 302,390	

17 Sep 03

LAKE TAHOE DESIGN CRITERIA ANALYSIS_ TASK LIST

1. Initial assessment

1.1. Assess existing practice and ongoing studies
Compile and Review Existing Lake Tahoe Design Standards and Regulations relevant to BMP design and other regulatory requirements. Review ongoing studies with regard to BMP and TMDL studies in the project area.

1.2. Define criteria/methods selection process, develop stakeholder consensus

Deliverable: Summary report describing state of the practice and consensus on needed criteria
Schedule: 15September-15 December 03

2. Data Base

Update existing Corps Data Base of gage hydro-meteorologic data, acquire geospatial data (land use, land cover, snow-water equivalent estimates), provide quality control/assurance

Deliverable: Databases of gage and geospatial data
Schedule: 15November-30January04

3. Precipitation/meteorological evaluation and analysis

3.1. Review current NWS depth-duration frequency study
Determine if study is at scale that is sufficient for the specification of depth-duration frequency curves for study area

3.2. Augment current depth-duration frequency study (as needed)
Incorporate additional data not used in previous studies, and GIS based methods for mapping precipitation depth-duration-frequency estimates.

3.3. Snow water equivalent mapping/frequency analysis
Develop spatial mapping of the frequency of basin-wide snow-water equivalent using GIS based methods for integrating various scales of snow observation

3.4. Develop design storms/antecedent conditions
Create a set of frequency based design storms (temporal and spatial distribution), as a function of duration and frequency and the corresponding antecedent watershed conditions. Short duration precipitation data is limited within basin. Need to evaluate value of gages outside basin to aid in creating events.

Deliverable: Report providing precipitation depth-duration frequency curves, snow-water equivalent mapping, and frequency based design storms with corresponding initial conditions
Schedule: 15December03-15February04

4. Flow frequency analysis

4.1. At-site flood (high flow) frequency analysis
Analyze region-wide gage (at-site) information to assess the applicability of the procedure used by federal agencies for flood analysis, estimate gage peak and volume-duration frequency curves

4.2. At-site low-flow frequency analysis
Obtain estimates of low-flow frequency curves at gages by applying best available estimation methods.

4.3. At-site flow-duration analysis
Obtain empirical flow-duration curves from gage data, determine a distribution can be use to describe these curves

4.4. Regional regressions for high flow frequency curves, low-flow frequency curves and flow-duration curves useful for ungaged watershed analysis
Use GIS base technology and data base information to develop watershed and meteorologic parameters for regional regression. Use best available regression techniques to develop regional regressions for gage frequency relationships developed in tasks 4.3-4.5. If regional regressions not significant, find alternative methods for regionalizing relationships.

Deliverable: Report describing gage frequency relations for low and high flows, gage flow-duration curves, and regional regressions relating watershed and meteorologic parameters to frequency estimates
Schedule: 15February04-31July04

5. Recommend precipitation-runoff modeling approaches

Provide recommendations regarding the methodologies to be used in perform precipitation runoff modeling. Recommendations will be based on the current practice, ongoing studies and applications/research in similar watersheds.

Deliverable: Report describing recommended modeling approaches
Schedule: 31July04-31August04
6. Summary Report

Provide draft report to stakeholders for review comments. Respond to review comments and compile final report.

Deliverable: Summary report
Schedule: 15July04-30September04